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EXPEDIENT GEOMETRY FOR THE DESIGN OF COMPOUND HIGHWAY CURVES WITH CONNECTION SPIRALS

by Robert D. Schacherl, A.M. ASCE,
and George J. Berindoague

HIGHWAY DIVISION

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EXPEDIENT GEOMETRY FOR THE DESIGN OF COMPOUND HIGHWAY CURVES WITH CONNECTION SPIRALS

Robert D. Schacherl,[1] A.M., ASCE and
George J. Berindoague[2]

This article sets forth an expedient method of calculating transition spirals when used as connections between compound curves on highway location.

The principles of this method have been used in the projection of the horizontal alignment for the 310 miles long Cochabamba—Santa Cruz Highway in Bolivia now under construction. This projection involved the calculation of more than 3000 curves with transition spirals.

Due to the mountainous character of the terrain involving very steep side hill slopes about 70% of these curves had to be compounded and it was considered impossible to locate the line directly on the ground. It was found necessary to prepare accurate contour maps based on a P—(preliminary) line traverse following only approximately the anticipated projected line. Then the L—(projected) line was designed on the contour maps, its accurate geometry established from P—line coordinates, and sufficient ties to the P—line calculated to enable the transit men to locate the projected line on the ground with frequent checks of accuracy. In some cases the discrepancies between the cross sections taken from the L-line established on the ground and those previously obtained from the contour maps were of such magnitude that shifting of the horizontal alignment was required; but generally it was possible to adjust such differences by slight modifications of the vertical alignment.

In view of the necessity of the above mentioned office design procedure it was not considered desirable to locate the center line of compound curves with connection spirals without first establishing the main tangents of a system of circular curves.

The points of intersection of the projected line were placed at distances and in a way which provide with long enough tangents and adequate intersection angles to allow for spirals of the lengths set forth and for circular curves of such length to permit the insertion of connection spirals. Anticipating approximately the shifting of the line produced by the subsequent offsetting for the insertion of spirals, first circular curves are assumed in such a manner as to obtain after insertion of the spirals a projected line in the situation desired. After some practice designers usually estimate very closely the offsetting referred to above.

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The cubic spiral as developed especifically for highways by the U.S. Bureau of Public Roads in Joseph Barnett's book entitled "Transition Curves for Highways" is the one used throughout the Cochabamba–Santa Cruz Highway. In this type of spiral the change in degree of curvature (arc definition) between any two points is proportional to the distance between them, (the lengths of spirals usually were chosen in conformity with PRA regulations) and its geometry when used as connection between curves of different radii is the topic of the subsequent discussions.

The standard nomenclature, definitions and formulae used by the U.S.B.P.R. as established in the book "Transition Curves for Highways" by Joseph Barnett, will be used.

A spiral connecting two circular curves of degrees of curvature D_{C1} and D_{C2} can be considered equivalent to a spiral which would be used between a tangent and a circular curve of degree $(D_{C2} - D_{C1})$. A line common to the two radii R_{C1} and R_{C2} bisects the connection spiral L_a, and the tangents to the circular curves at the points of intersection between the circular curves and the common radius line are parallel and separated by the distance p_a. The offset p_a between the two circular curves is for practical purposes equal to the difference between p_2 and p_1, the offsets of the circular curves, in the assumed case that they are connected to a main tangent by transitions L_{S2} and L_{S1} of length equal to L_a. (See Fig. 1.)

The offset p_a as obtained in accordance with the former statement by substraction of p_1 from p_2 differs slightly from p_a calculated by the use of the equivalent spiral angle θ_a.

In the following example the difference between p_a calculated by the use of the equivalent spiral angle θ_a and the value $(p_2 - p_1)$ is demonstrated:

Example No. 1.

Given: A compound curve of $D_{C1} = 14^\circ$ and $D_{C2} = 25^\circ$ with a connecting spiral of 150 ft.

Required: To demonstrate the difference between p_a and $(p_2 - p_1)$.

Solution:

$$\theta_a = \frac{L_a}{200}(D_{C2} - D_{C1}) = \frac{150}{200}(25^\circ - 14^\circ) = 8.25^\circ$$

Using Table II of "Transition Curves for Highways" by Joseph Barnett for coefficients of p_a, p_1, and p_2:

$$\theta_{S2} = \frac{L_{S2}}{200} D_{C2} = \frac{150}{200} 25^\circ = 18.75^\circ, \quad \begin{aligned} p_a &= 0.011995 \times 150 = 1.799' \\ p_2 &= 0.02716 \times 150 = 4.074' \end{aligned}$$

$$\theta_{S1} = \frac{150}{200} 14^\circ = 10.50^\circ, \quad p_1 = 0.01526 \times 150 = 2.289'$$

$$p_a \text{ (approximate)} = (p_2 - p_1) = (4.074 - 2.289) = 1.785'$$

$$\text{Difference } p_a - (p_2 - p_1) = 0.014'$$

This difference of 0.014' has been found to be very close to the maximum difference possible for transitions of minimum length chosen for

the respective radii and design speeds from Table I of the book "Transition Curves for Highways" by Joseph Barnett, 1940 edition. As within the ranges of said Table I the maximum difference has been found to occur for a transition of minimum length of 150 ft. the corresponding percentage of difference also is a maximum. Expressing the difference of our specific example in conventional terms of precision related to the length of traverse, an inaccuracy of $\frac{150}{0.014} = 1$ in 10714 results. The precision required for preliminary and located lines usually ranges from 1 in 3000 to 1 in 5000; and as the connexion spirals usually represent a limited percentage of the total length of a line, the small differences in p_a referred to above generally do not reflect a serious factor in the accuracy of highway location.

However, if spirals outside of the ranges of the minimum transition lengths recommended in Table I of the book "Transition Curves for Highways" by Joseph Barnett are used, it may be necessary to evaluate the difference in p_a before its approximate value $(p_2 - p_1)$ is used.

Accepting that for practical purposes p_a and $(p_2 - p_1)$ are interchangeable, a simple method of providing for the insertion of transitions of equal length in a system of compound curves at the P.C. each P.C.C. and P.T. results by maintaining the center of each circular curve at the bisector of its respective central angle, offsetting the circular curve from both main tangents by its respective p, calculated for the assumed case that the circular curve is connected to a main tangent; then each transition is inserted to replace the produced portions of both circular curves it connects.

As an illustration of the method proposed the calculations for the characteristics of a four PI compound curve will be developed in Example No. 2. In order to show a very general case the first three curves are assumed to become progressively sharper while the fourth curve is flatter than the third and in addition thereto assumed to be transitional throughout. Form No. 1 developed for the expedient organization and sequence of computations will be demonstrated and used as well as the graphs basically shown hereon. These graphs were conceived by the writers and are excerpts from a set covering the ranges of transitions of minimum length, (150', 200', 250', 300', 350', and 400'), chosen for the respective radius and design speed from Table I of the book "Transition Curves for Highways" by Joseph Barnett. This set is in the process of being developed with the aid of Table V of the above mentioned book. In order to read them to the nearest hundredth of a foot their original size is larger carrying more subdivisions than the reproductions shown herein.

Example No. 2.—(Refer to Fig. 2)
Given: Distances between PIs as calculated from their coordinates:

PI No. 10 - PI No. 11 = 731.03 ft.
PI No. 11 - PI No. 12 = 424.10 ft.
PI No. 12 - PI No. 13 = 321.25 ft.

Intersection angles as calculated from the tangent's bearings:

$\Delta_{11} = 15^\circ\ 16'$

$\Delta_{12} = 16^\circ\ 48'$

$\Delta_{13} = 37^\circ\ 12'$

$\Delta_{14} = 10^\circ\ 10'$

Design speed = 40 miles per hour

L_S = 150 ft.; L_a = 150 ft.

Station S.T. at PI No. 10 = 8 + 21.22

T_S at PI No. 10 = 212.25 ft.

By scaling from the projection, T_{11} = 265 ft.

Required: To establish a compound curve connected with transition spirals; curve at PI No. 14 to be transitional throughout.

Solution: (Refer to Fig. 3)

PI No. 11.

Fill in Form No. 1, (sheet 11) with the known data: PI No. 11, $\Delta = 15^\circ\ 16'$, $\Delta/2 = 7^\circ\ 38'$, L_S = 150 ft., L_a = 150 ft., T_{11} = 265, and at the bottom of the sheet the distance from PI No. 10 to PI No. 11 = 731.03 ft., T_S (back) = 212.25 ft. Station S.T. (back) = 8 + 21.22.

The following values are computed in the sequence followed hereon by the respective formulae and the results inserted at the respective designations.

(1) $(R_c + p) = \dfrac{T}{\text{tg}\,\Delta/2} = \dfrac{265.00}{\text{tg}\ 7^\circ\ 38'} = 1977.32$ ft.

Entering GRAPH 1 with $(R_c + p) = 1977.32$, p = 0.47 ft.

$R_c = (R_c + p) - p = 1977.32 - 0.47 = 1976.85$ ft.

Entering GRAPH 2 with $R_c = 1976.85$, k = 75.00, L.C. = 149.99

Entering GRAPH 3 with $R_c = 1976.85$, x = 149.98

Entering GRAPH 4 with $R_c = 1976.85$, y = 1.89

(2) $T_S = (T + k) = 265.00 + 75.00 = 340.00$ ft.

(3) $D_c = \dfrac{5729.58}{R_c} = \dfrac{5729.58}{1976.85} = 2.8983^\circ$

(4) $\theta_S = \dfrac{L_S}{200} D_c = \dfrac{150}{200} 2.8983^\circ = 2.1737^\circ$

(5) $\Delta_c = \Delta - 2\theta_S = 15.2667^\circ - 4.3474^\circ = 10.9193^\circ$

(6) $L_c = 100 \dfrac{\Delta_c}{D_c} = 100 \dfrac{10.9193^\circ}{2.8983^\circ} = 376.75$ ft.

The characteristics of the connexion spiral No. 1 cannot be figured before the curve at PI No. 12 is calculated, therefore formulae (7) through (9) will be used later.

The stationing at the T.S., S.C., C.S., and S.C. is obtained by the operations shown at the bottom of Form No. 1 (sheet 11).

PI No. 12.

Fill in Form No. 1 (sheet 12) the known data: PI No. 12, $\Delta = 16^\circ 48'$, $\Delta/2 = 8^\circ 24'$, (the assumed $L_S = 150$ ft.) $L_a = 150$ ft., Distance from PI No. 11 to PI No. 12 = 424.10 ft., T_{11} (back) = 265.00, thus T_{12} (ahead) = 424.10 - 265.00 = 159.10 ft. Station S.C. = 16 + 76.75.

The following values are computed, and tabulated on sheet 12, Form No. 1.

(1) $$(R_c + p) = \frac{159.10}{\text{tg } 8^\circ 24'} = 1077.40 \text{ ft.}$$

Entering GRAPH 1 with $(R_c + p) = 1077.40$, $p = 0.87$ ft.

$$F_c = (R_c + p) - p = 1076.53 \text{ ft.}$$

The values of k, L.C., x, and y are omitted as they only are of use for spirals running into a tangent.

(3) $$D_c = \frac{5729.58}{1076.53} = 5.3223^\circ$$

(4) $$\theta_s = \frac{150}{200} 5.3223^\circ = 3.9917^\circ$$

(5) $$\Delta_c = 16.8000^\circ - 7.9834^\circ = 8.8166^\circ$$

(6) $$L_c = 100 \frac{8.8166}{5.3223} = 165.65 \text{ ft.}$$

The following characteristics of the connection spiral No. 1 calculated by formulae (7) through (9) are tabulated on sheet 11 of Form No. 1.

(7) $$\theta_a = \theta_{S2} - \theta_{S1} = 3.9917^\circ - 2.1737^\circ = 1.8180^\circ$$

(8) $$\Delta_a = \theta_{S2} + \theta_{S1} = 3.9917^\circ + 2.1737^\circ = 6.1654^\circ = 6^\circ 09.9'$$

(9) $$p_a = p_2 - p_1 = 0.87 - 0.47 = 0.40 \text{ ft.}$$

The stationing is listed on the bottom of sheet 12. Form No. 1.

PI No. 13.

The characteristics of the curve at PI No. 13 and of connection spiral No. 2 are calculated in a similar way to PI No. 12. They are listed on Form No. 1, sheets 13 and 12.

PI No. 14.—(Transitional throughout)

Fill in Form No. 1, sheet 14 the known data: PI No. 14, $\Delta = 10^\circ 10'$, $\Delta/2 = 5^\circ 05'$, $L_S = 150$ ft., $L_a = 150$ ft., Station S.C.S. = 23 + 03.95.

The following values are computed and tabulated on sheet 14 of Form No. 1:

(10) $$\theta_s = \Delta/2 = 5^\circ 05' = 5.0833^\circ$$

(11) $D_c = \frac{200}{L_s}\ \theta_s = \frac{200}{150}\ 5.0833^\circ = 6.7777^\circ$

(3) $R_c = \frac{5729.58}{D_c} = \frac{5729.58}{6.7777} = 845.36$ ft.

The following values of p, k, L.C., x, and y are obtained from GRAPHS 1 through 4 in a similar way as in the computations concerning PI No. 11:

$p = 1.11$, $k = 74.98$, $x = 149.88$, $y = 4.43$, and L.C. = 149.95

(The value of y is obtained from the third sheet of GRAPH 4 which is not shown hereon.)

(1) $T = (R_c + p)\,tg\ \Delta/2 = (845.36 + 1.11)\,tg\ 5^\circ\ 05' = 75.29 = T_{14}$

The distance from PI No. 13 to PI No. 14 is,
$T_{13} + T_{14} = 162.15 + 75.29 = 237.44$ ft.

(2) $T_S = T + k = 75.29 + 74.98 = 150.27$ ft.

The characteristics of the connection spiral No. 3 calculated by formulae (7) through (9) are tabulated on sheet 13 of Form No. 1.

The stationing is listed on the bottom of sheet 14 of Form No. 1.

The complete horizontal alignment data concerning PIs No. 11 through 14 as calculated above are given on the plan shown in Fig. 4 (superelevations and widenings are not shown).

The calculations referring to the foregoing example also could have been performed less rapidly using Table V of "Transition Curves for Highways" by Joseph Barnett in lieu of its extension by GRAPHS 1 through 4. In this case, once the value $(R_c + p)$ is known, the p value in accordance with the D_c corresponding to a radius $(R_c + p)$ is subtracted from $(R_c + p)$ to obtain the first trial value of R_c, then the corresponding D_c is calculated again and the new p corresponding to the recently obtained D_c is figured and subtracted from $(R_c + p)$ to obtain the second (closer) trial value of R_c, and the preceding operation is carried on until the value obtained for p remains constant.

On the other hand the graphs give direct solutions and without the need of interpolations.

With the exception of formula (9) completely explained, formulae (1) through (11) exposed in Example No. 2 are well known formulae or in some cases were derived from such formulae which can be found in "Transition Curves for Highways" by Joseph Barnett. Formula (5) $\Delta_c = \Delta - 2\theta_s$ is given in the above mentioned book for single center curves but also holds for compound curves with connection spirals of equal length since $\Delta_1 = \frac{L_a}{200}\ D_{c1}$ and $\Delta_2 = \frac{L_a}{200}\ D_{c2}$ which for $L_s = L_a$ and for the same degree of curvature produce the same results as $\theta_s = \frac{L_s}{200}\ D_c$. In a similar way formulae (7) and (8) covering θ_a and Δ_a are interchangeable with the general formulae since,

$$\theta_a = \theta_{S2} - \theta_{S1} \quad \text{or,}$$

$$\frac{L_a}{200}(D_{C2} - D_{C1}) = \frac{L_S D_{C2}}{200} - \frac{L_S D_{C1}}{200}$$

and $\Delta_a = \Delta_2 + \Delta_1 = \theta_{S2} + \theta_{S1} = \frac{L_S D_{C2}}{200} + \frac{L_S D_{C1}}{200}$ (See Fig. 1)

provided $L_S = L_a$.

In the rare cases where due to special conditions in a compound curve the use of spirals of unequal length is imperative, the centers of all circles can no longer be maintained at the bisectors of the respective central angles due to the fact that the two p values concerning the same "produced" circle are different varying with the length of the spirals. In these cases the following modifications of the design method described may be used:

The first curve is computed offsetting the corresponding amount p from its end tangent and coming tangent to the original tangent ahead. The next curve is computed by the trial method, offsetting from the tangent back the corresponding amount p_a inward or outward respectively for a curve sharper or flatter than the preceding one, and coming tangent to the tangent ahead, except for the case that this is an end tangent. The following curves are computed the same way except the last one which is offset the respective amount p_a from the tangent to the foregoing curve and the corresponding amount p from the end tangent. In a two center compound curve the second curve is computed in the same manner as the last curve of a multicenter curve.

This method results rather complicated and cumbersome and would require the skill of a highly qualified designer because all but the first curve of a compound system are to be calculated by trial methods involving also the repeated trigonometrical calculations of variations in tangent distances due to the variations produced in the consecutive approximations of p and p_a values.

In view of the foregoing expositions it is considered desirable to avoid, where possible, the use of different spiral lengths in any one compounded system of curves, in order to be able to follow the expedient calculation method illustrated in Example No. 2.

The writers gratefully wish to acknowledge Mr. Gerald S. Rinehart, M.ASCE Project Engineer for "Knappen Tippetts Abbett McCarthy Engineers" for the permission granted to use data applied in the projection of the Cochabamba-Santa Cruz Highway; Mr. Joseph Barnett, and the U. S. Bureau of Public Roads as free reference has been made to their publications.

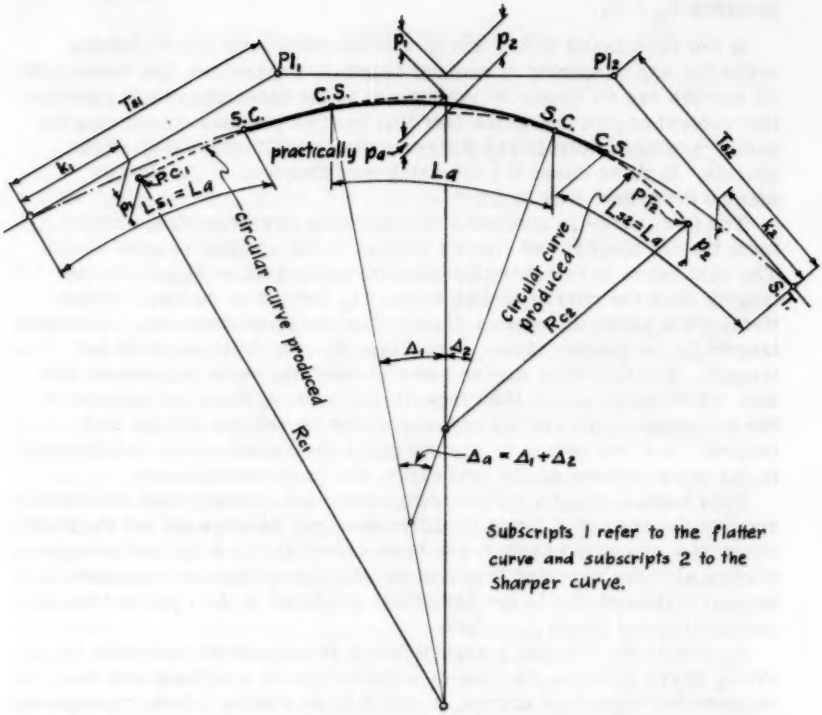


FIG. 1. The offset p_a between two circular curves of radii R_{c1} and R_{c2}, connected by a transition spiral L_a is practically equal to the difference between p_2 and p_1, the offsets of the circular curves if the were connected to main tangents by the assumed spirals L_{s1} and L_{s2} of length equal to L_a.

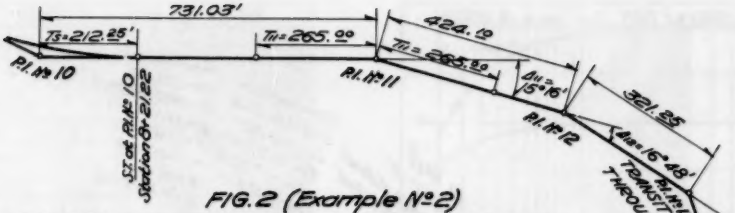


FIG. 2 (Example N° 2)

Establish a compound curve from P.I. N° 11 to P.I. N° 14. Δ_{11} through Δ_{14} are given and the distances and station shown.
As the curve at P.I. N° 14 is to be transitional throughout the tangent distance P.I. N° 13 - P.I. N° 14 cannot be given; said distance will result from the computations concerning P.I. N° 14.

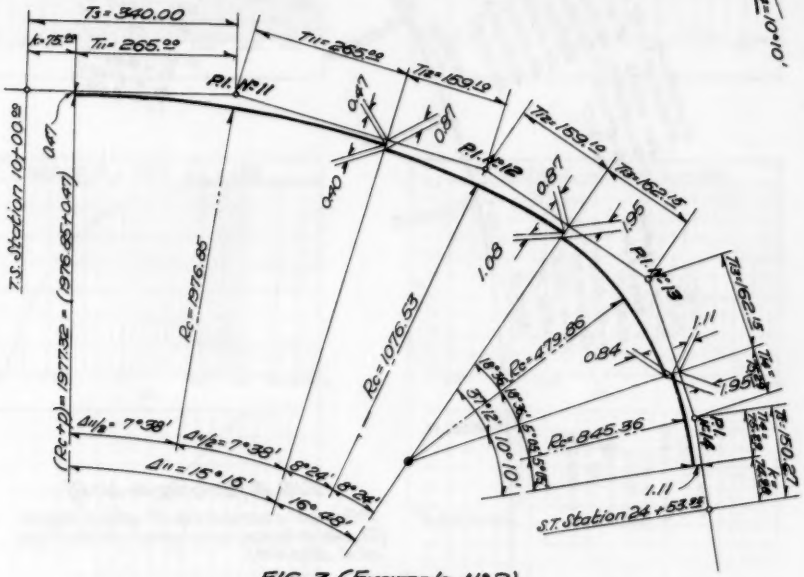
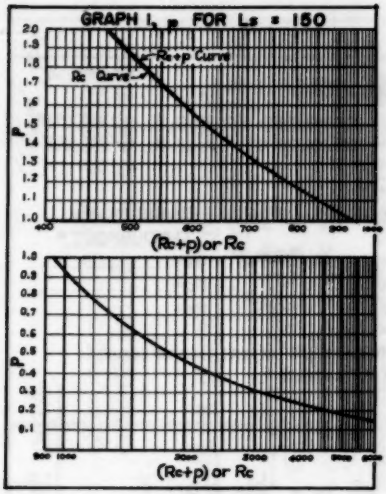
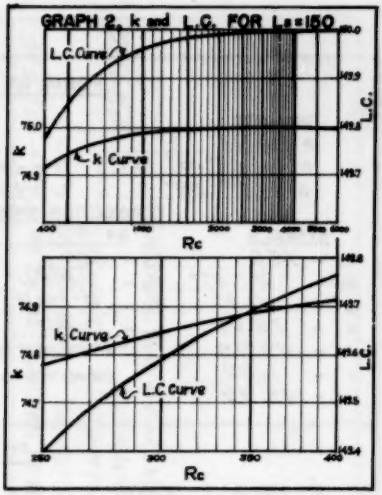
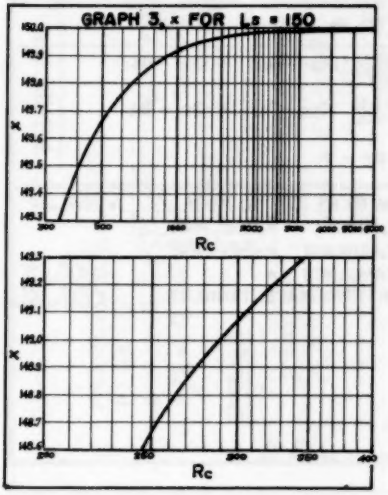


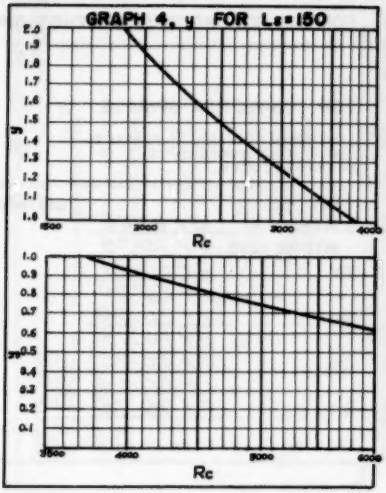
FIG. 3 (Example N° 2)
Produced circular curves of compound curve, (Spirals not shown)

FIG. 4 (Example N° 2)
Plan of complete & alignment
(Superelevations and widenings
not shown).


GRAPH 1, p FOR Ls = 150
Rc+p Curve
Rc Curve
p
(Rc+p) or Rc
p
(Rc+p) or Rc


GRAPH 2, k and L.C. FOR Ls=150
L.C. Curve
k Curve
k
L.C.
Rc
k Curve
L.C. Curve
k
L.C.
Rc


GRAPH 3, x FOR Ls = 150
x
Rc
x
Rc


GRAPH 4, y FOR Ls=150
y
Rc
y
Rc

(Sheet 11)

FORM Nº 1, CURVE DATA

PROJECT

P.I. Nº 11

COMPUTED BY: R.D.S. 6/26/53

CHECKED BY: G.J.B. 6/26/53

Δ = 15°16' RT Ts = 340.00 Bk.

Δ/2 = 7° 38' T// = 265.00 Ah.

SPIRALS	CONNECTION SPIRAL Nº 1	CIRCULAR CURVE	TRANSITIONAL THROUGHOUT *
Ls = 150'	La = 150'	Dc = 2.8983°	θs =
θs = 2.1737°	θa = 1.8180°	Rc = 1976.85	Dc =
p = 0.47	Δa = 6°09.9'	Δc = 10°55.2'	Rc =
k = 75.00	pa = 0.40	Lc = 376.75	
x = 149.98			
y = 1.89			
L.C. = 149.99			

* "TRANSITIONAL THROUGHOUT" REFERS ONLY TO CURVES CONNECTED TO ONE OR TWO TANGENTS.

FORMULAE

① $(Rc + p) = \frac{T}{tg\,\Delta/2}$

② $Ts = (T + k)$

③ $Dc = \frac{5729.58}{Rc}$

④ $\theta s = \frac{Ls}{200} \times Dc$

⑤ $\Delta c = \Delta - 2\theta s$

⑥ $Lc = 100\,\frac{\Delta c}{Dc}$

FOR CURVES TRANSITIONAL THROUGHOUT *: ⑭ $\theta s = \Delta/2$ ⑭ $Dc = \frac{200}{Ls} \times \theta s$

FOR CONNECTION SPIRALS:

⑦ $\theta a = \frac{La}{200}(Dc_2 - Dc_1) = \theta s_2 - \theta s_1$

⑧ $\Delta a = \frac{La}{200}(Dc_2 + Dc_1) = \theta s_2 + \theta s_1$

⑨ $pa = p_2 - p_1$

SUBSCRIPTS 1 REFER TO FLATTER CURVE AND SUBSCRIPTS 2 TO SHARPER CURVE.

STATIONS.	
S.T. (BACK)	8+21.22
INTERM. TANG.	1+78.78
T.S.	10+00.00
Ls	1+50.00
S.C.	11+50.00
Lc	3+76.75
C.S.	15+26.75
La	1+50.00
S.C.	16+76.75

DISTANCE FROM P.I. Nº 10 TO P.I. Nº 11 = 731.03

Ts (BACK)	= 212.25	
Ts (AHEAD)	= 340.00	
Σ TANGENTS	=	552.25
INTERMEDIATE TANGENT		178.78

(Sheet 12)

FORM Nº 1, CURVE DATA

PROJECT _____ COMPUTED BY: R.D.S. 6/26/53

P.I. Nº 12 CHECKED BY: G.J.B. 6/26/53

Δ = 16° 48' RT $T_{1/2}$ = 159.10 Bk.

Δ/2 = 8° 24' $T_{1/2}$ = 159.10 Ah.

SPIRALS	CONNECTION SPIRAL Nº 2	CIRCULAR CURVE	TRANSITIONAL THROUGHOUT *
Ls = 150'	La = 150'	Dc = 5.3223°	θs =
θs = 3.9917°	θa = 4.9634°	Rc = 1076.53	Dc =
p = 0.87	Δa = 12° 56.8'	Δc = 8° 49.0'	Rc =
k =	pa = 1.08	Lc = 165.65	
x =			
y =			
L.C. =			

* "TRANSITIONAL THROUGHOUT" REFERS ONLY TO CURVES CONNECTED TO ONE OR TWO TANGENTS.

STATIONS		DISTANCE FROM P.I. Nº 11 TO P.I. Nº 12 = 424.10	
S.T.(BACK)		T_1 (BACK) = 265.00	
INTERM. TANG.		T_2 (AHEAD) = 159.10	
T.S.		Σ TANGENTS =	424.10
L.S.		INTERMEDIATE TANGENT	0
S.C.	16 + 76.75		
Lc	1 + 65.65		
C.S.	18 + 42.40		
La	1 + 50.00		
S.C.	19 + 92.40		

For formulae omitted see sheet 1 of Form Nº 1

(Sheet 13)

FORM Nº 1, CURVE DATA

PROJECT _____ COMPUTED BY: R.D.S. 6/26/53

P.I. Nº 13 CHECKED BY: G.V.B. 6/26/53

Δ = 37°12' RT T_{13} = 162.15 Bk.

Δ/2 = 18°36' T_{13} = 162.15 Ah.

SPIRALS	CONNECTION SPIRAL Nº 3	CIRCULAR CURVE	TRANSITIONAL THROUGHOUT *
Ls = 150'	La = 150'	Dc = 11.9401°	θs =
θs = 8.9551°	θa = 3.8718°	Rc = 479.86	Dc =
p = 1.95	Δa = 14°02.3'	Δc = 19°17.4'	Rc =
k =	pa = 0.84	Lc = 161.55	
X =			
Y =			
L.C. =			

* "TRANSITIONAL THROUGHOUT" REFERS ONLY TO CURVES CONNECTED TO ONE OR TWO TANGENTS.

STATIONS		DISTANCE FROM P.I. Nº 12 TO P.I. Nº 13 = 321.25	
S.T. (BACK)		T_d (BACK) = 159.10	
INTERM. TANG.		T_d (AHEAD) = 162.15	
T.S.		ΣTANGENTS =	321.25
Ls		INTERMEDIATE TANGENT	0
S.C.	19+92.40		
Lc	1+61.55		
C.S.	21+53.95		
La	1+50.00		
S.C.S.	23+03.95		

For formulae omitted see sheet 1 of Form Nº 1

500-14

FORM Nº 1, CURVE DATA

(Sheet 14)

PROJECT _____

P.I. Nº 14

COMPUTED BY: R.O.S. 6/26/53

CHECKED BY: G.J.B. 6/26/53

Δ = 10° 10' RT Tf = 75.29 Bk.

Δ/2 = 5° 05' Ts = 150.27 Ah.

SPIRALS	CONNECTION SPIRAL Nº ____	CIRCULAR CURVE	TRANSITIONAL THROUGHOUT *
Ls = 150'	La =	Dc =	θs = 5.0833°
θs = 5.0833°	θa =	Rc =	Dc = 6.7777°
p = 1.11	Δa =	Δc =	Rc = 845.36
k = 74.98	pa =	Lc =	
x = 149.88			
y = 4.93			
L.C. = 149.95			

* "TRANSITIONAL THROUGHOUT" REFERS ONLY TO CURVES CONNECTED TO ONE OR TWO TANGENTS.

STATIONS

S.T.(BACK) _____

INTERM. TANG. _____

T.S. _____

L.S. _____

S.C. _____

Lc. _____

S.C.S. 23+03.95

Ls 1+50.00

S.T. 24+53.95

DISTANCE FROM P.I. Nº 13 TO P.I. Nº 14 = 237.44

Ts (BACK) = 162.15

Ts (AHEAD) = 75.29

Σ TANGENTS = 237.44

INTERMEDIATE TANGENT 0

For formulae omitted see sheet 1 of Form Nº 1

500-15

PROCEEDINGS-SEPARATES

The technical papers published in the past year are presented below. Technical-division sponsorship is indicated by an abbreviation at the end of each Separate Number, the symbols referring to: Air Transport (AT), City Planning (CP), Construction (CO), Engineering Mechanics (EM), Highway (HW), Hydraulics (HY), Irrigation and Drainage (IR), Power (PO), Sanitary Engineering (SA), Soil Mechanics and Foundations (SM), Structural (ST), Surveying and Mapping (SU), and Waterways (WW) divisions. For titles and order coupons, refer to the appropriate issue of "Civil Engineering" or write for a cumulative price list.

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SEPTEMBER: 260(AT), 261(EM), 262(SM), 263(ST), 264(WW), 265(ST), 266(ST), 267(SA), 268(CO), 269(CO), 270(CO), 271(SU), 272(SA), 273(PO), 274(HY), 275(WW), 276(HW), 277(SU), 278(SU), 279(SA), 280(IR), 281(EM), 282(SU), 283(SA), 284(SU), 285(CP), 286(EM), 287(EM), 288(SA), 289(CO).

OCTOBER:[b] 290(all Divs), 291(ST)[a], 292(EM)[a], 293(ST)[a], 294(PO)[a], 295(HY)[a], 296(EM)[a], 297(HY)[a], 298(ST)[a], 299(EM)[a], 300(EM)[a], 301(SA)[a], 302(SA)[a], 303(SA)[a], 304(CO)[a], 305(SU)[a], 306(ST)[a], 307(SA)[a], 308(PO)[a], 309(SA)[a], 310(SA)[a], 311(SM)[a], 312(SA)[a], 313(ST)[a], 314(SA)[a], 315(SM)[a], 316(AT), 317(AT), 318(WW), 319(IR), 320(HW).

NOVEMBER: 321(ST), 322(ST), 323(SM), 324(SM), 325(SM), 326(SM), 327(SM), 328(SM), 329(HW), 330(EM)[a], 331(EM)[a], 332(EM)[a], 333(EM)[c], 334(EM), 335(SA), 336(SA), 337(SA), 338(SA), 339(SA), 340(SA), 341(SA), 342(CO), 343(ST), 344(ST), 345(ST), 346(IR), 347(IR), 348(CO), 349(ST), 350(HW), 351(HW), 352(SA), 353(SU), 354(HY), 355(PO), 356(CO), 357(HW), 358(HY).

DECEMBER: 359(AT), 360(SM), 361(HY), 362(HY), 363(SM), 364(HY), 365(HY), 366(HY), 367(SU)[c], 368(WW)[c], 369(IR), 370(AT)[c], 371(SM)[c], 372(CO)[c], 373(ST)[c], 374(EM)[c], 375(EM), 376(EM), 377(SA)[c], 378(PO)[c].

VOLUME 80 (1954)

JANUARY: 379(SM)[c], 380(HY), 381(HY), 382(HY), 383(HY), 384(HY)[c], 385(SM), 386(SM), 387(EM), 388(SA), 389(SU)[c], 390(HY), 391(IR)[c], 392(SA), 393(SU), 394(AT), 395(SA)[c], 396(EM)[c], 397(ST)[c].

FEBRUARY: 398(IR)[d], 399(SA)[d], 400(CO)[d], 401(SM)[c], 402(AT)[d], 403(AT)[d], 404(IR)[d], 405(PO)[d], 406(AT)[d], 407(SU)[d], 408(SU)[d], 409(WW)[d], 410(AT)[d], 411(SA)[d], 412(PO)[d], 413(HY)[d].

MARCH: 414(WW)[d], 415(SU)[d], 416(SM)[d], 417(SM)[d], 418(AT)[d], 419(SA)[d], 420(SA)[d], 421(AT)[d], 422(SA)[d], 423(CP)[d], 424(AT)[d], 425(SM)[d], 426(IR)[d], 427(WW)[d].

APRIL: 428(HY)[c], 429(EM)[c], 430(ST), 431(HY), 432(HY), 433(HY), 434(ST).

MAY: 435(SM), 436(CP)[c], 437(HY)[c], 438(HY), 439(HY), 440(ST), 441(ST), 442(SA), 443(SA).

JUNE: 444(SM)[e], 445(SM)[e], 446(ST)[e], 447(ST)[e], 448(ST)[e], 449(ST)[e], 450(ST)[e], 451(ST)[e], 452(SA)[e], 453(SA)[e], 454(SA)[e], 455(SA)[e], 456(SM)[e].

JULY: 457(AT), 458(AT), 459(AT)[c], 460(IR), 461(IR), 462(IR), 463(IR)[c], 464(PO), 465(PO)[c].

AUGUST: 466(HY), 467(HY), 468(ST), 469(ST), 470(ST), 471(SA), 472(SA), 473(SA), 474(SA), 475(SM), 476(SM), 477(SM), 478(SM)[c], 479(HY)[c], 480(ST)[c], 481(SA)[c], 482(HY), 483(HY).

SEPTEMBER: 484(ST), 485(ST), 486(ST), 487(CP)[c], 488(ST)[c], 489(HY), 490(HY), 491(HY)[c], 492(SA), 493(SA), 494(SA), 495(SA), 496(SA), 497(SA), 498(SA), 499(HW), 500(HW), 501(HW)[c], 502(WW), 503(WW), 504(WW)[c], 505(CO), 506(CO)[c], 507(CP), 508(CP), 509(CP), 510(CP), 511(CP).

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a. Presented at the New York (N.Y.) Convention of the Society in October, 1953.
b. Beginning with "Proceedings-Separate No. 290," published in October, 1953, an automatic distribution of papers was inaugurated, as outlined in "Civil Engineering," June, 1953, page 66.
c. Discussion of several papers, grouped by Divisions.
d. Presented at the Atlanta (Ga.) Convention of the Society in February, 1954.
e. Presented at the Atlantic City (N.J.) Convention in June, 1954.

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